Anatomy of the Heart

Introduction

This first lesson in the Structure and Function island provides an overview of the heart and great vessels, the anatomic locations of these structures, and where they are relative to the mediastinum. The histology of myocytes is discussed later in Structure and Function #4: *Heart as a Muscle*. The coronary vessels are discussed separately in the CAD island. The embryology and formation of the chambers and valves are discussed in the Plumbing island. Each cardiology lesson is designed to lay the foundations necessary for understanding the lessons that follow. This is the first "true" cardiology lesson, so it will act as an orientation and warmup rather than give high-yield facts. This lesson is not intended as an introduction to the module, per se, but we do point you towards those places in the notes that go into greater detail on a given topic.

Thorax and Mediastinum

Although it's not a difficult subject to master, the mediastinum can be very confusing if you believe that the mediastinum is an actual thing and not an arbitrary construct created by anatomists and surgeons to effectively communicate with each other asynchronously. The mediastinum is a concept used to understand spatial relationships in the chest.

You can think of the thorax as everything contained by the rib cage. The sternum in front has articular cartilage that joins it to the bones of the rib cage, which wrap around the body to articulate with the cartilage of the spine. The inferior boundary of the thorax is the diaphragm. And although there is no strict superior boundary, the neck region is considered the thoracic outlet. Then anatomists and surgeons got to naming things, and ooh, does it get frustrating. The thorax is divided up based on Body Cavities. No one explains the material this way, and this may be the first time you've encountered the concept of a Body Cavity. Body Cavities are fluid-filled sacs lined with a simple squamous epithelium called **mesothelium**. Each fluid-filled sac lined with mesothelium is named for the particular organ it's affiliated with. The Body Cavity near the heart is the **pericardial cavity**, the Body Cavity near the lungs is the **pleural cavity**, and the one associated with the viscera of the gut is called the **peritoneal cavity**. That last name doesn't make sense, but the point is that someone started calling them "cavities." They are not potential spaces where something can go (that would be a literal cavity)—they are fluid-filled sacs lined with mesothelium. Dr. Williams made "Body Cavity" a capitalized, proper noun in protest against those who thought it was a good idea to name a fluid-filled sac lined with mesothelium a cavity. We'll discuss this more in the pericardial disease lesson as well. Right now, Body Cavities are how we are going to explain the thorax.

Body Cavities create a literal barrier between organs. They enable the organs to slide past one another, separated by the small amount of fluid within the Cavities. Without them, one organ would adhere to another through tissue called adventitia. The thorax is divided into three columns in the anteroposterior plane, through a person's sternum. The outer two columns are the lungs. Each lung is encased in its own pleural cavity, its own Body Cavity. So, the center column, an arbitrarily chosen space in the thorax that is neither lung nor the Body Cavity of a lung, is the **mediastinum**.

Anatomists arbitrarily chose the boundaries of the mediastinum based on the lungs' pleural cavities, and then went on to arbitrarily divide the mediastinum based on the heart's **pericardial cavity** (the heart being the only other organ in the thorax with its own Body Cavity) and the sternal angle. The great vessels—the aorta and pulmonary artery—emerge from the heart and pericardial cavity at about the sternal angle. This relative anatomy made for a convenient correlation. Even though there is variability between humans, that variability is small enough that anatomists can communicate using an easily identifiable (and X-rayable) bone as a landmark. The heart has a pericardial cavity, but the great vessels do not. In every human, the pericardial cavity ends at the emergence of the great vessels, which is somewhere near the sternal angle, so that's where anatomists decided the mediastinum should be divided.

Seen from the side, above the sternal angle is the **superior mediastinum**. The superior mediastinum is confluent with the neck; there is no border between them. Below the sternal angle is the **inferior mediastinum**. But that's not how medical science named them. According to medical science, there is a superior, anterior, middle, and posterior mediastinum. BOGUS. That implies that there are four equally sized, relative mediastina. But where is the inferior mediastinum in that list? OHHHH. What is meant by that is that there is one superior mediastinum above (superior to) the inferior mediastinum, and the inferior mediastinum is subdivided into the anterior inferior, middle inferior, and posterior inferior mediastinum. We will explicitly state this fact so that it's easy to follow in the illustration below. The **anterior inferior mediastinum** is below the sternal angle and in front of the heart ("anterior mediastinum"), the **middle inferior mediastinum** is the heart within the pericardial cavity, and the **posterior inferior mediastinum** is everything behind the heart, which is continuous with the **superior mediastinum**, which is also continuous with the neck.

You swallow food. The food goes from your mouth into your esophagus. The esophagus (which is behind the trachea until the trachea branches into bronchi) carries the food through the superior and posterior inferior mediastina to your stomach, which is below the diaphragm. The esophagus must be physically present to do this task, but the point is that the neck, superior mediastinum, and inferior mediastinum are all continuous.

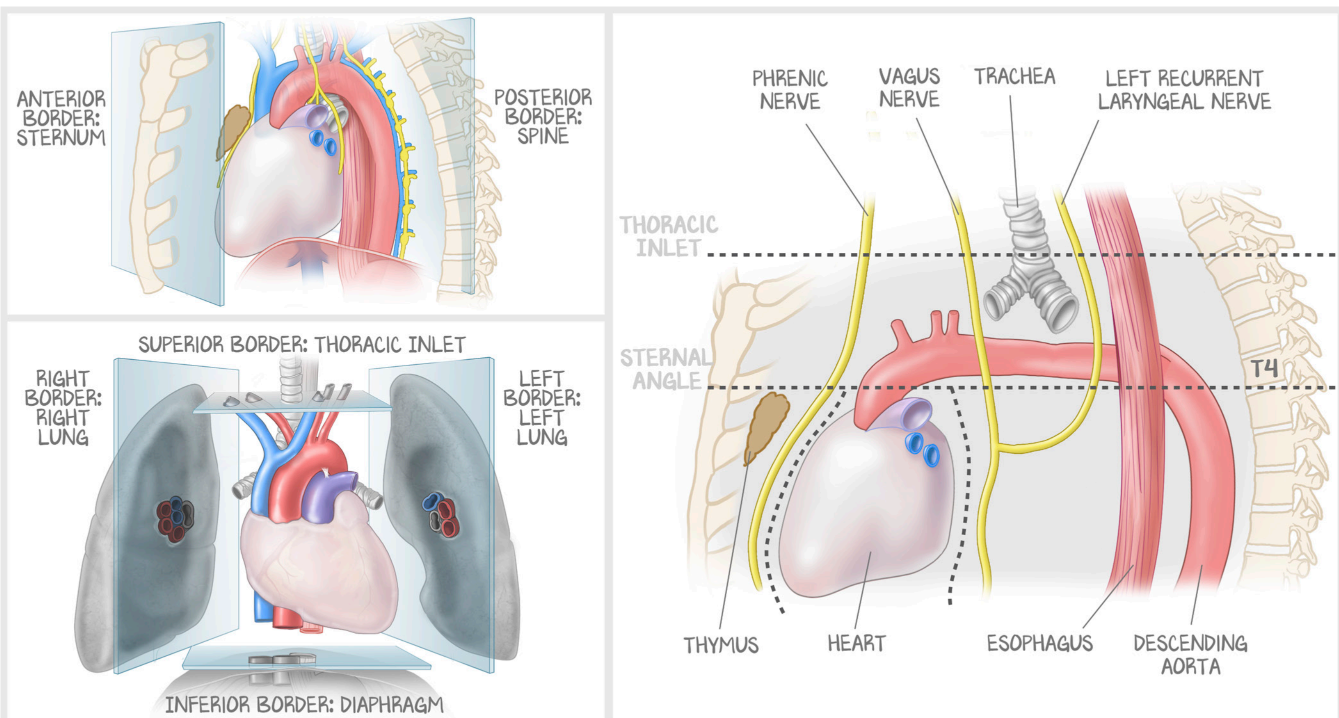

Figure 1.1: Mediastinal Organization
Rather than a traditional representation of the mediastinum, we've chosen different ways to illustrate the borders of the mediastinum and exaggerate what will be on your licensing exam. The anterior and posterior borders are the sternum and spine, respectively. The lateral borders of the mediastinum are the lungs. The superior border isn't a border but rather the thoracic inlet. The inferior border is the diaphragm. On the right, we provide an exaggerated diagram of the mediastinum divided into four compartments. We also exaggerate the anterior-posterior relationships of the organs, specifically showing that the aorta starts anterior in the superior mediastinum and becomes posterior in the inferior mediastinum.

The **middle inferior mediastinum** (middle = heart) is the heart and pericardial cavity.

The **anterior inferior mediastinum** (front = thymus) is a small space between the sternal body and the anterior fibrous pericardium. This is where the **thymic shadow** can be seen in children. In adults, there is not much here—lymph nodes, fat, and internal thoracic vessels.

The **posterior inferior mediastinum** (back = everything else) is between the vertebrae and the posterior fibrous pericardium. This is where everything else is. The **esophagus**, **trachea**, **aorta**, **vena cava**, the **hemiazygos veins**, **all the autonomics**, and all the **nerves** (except the phrenic nerve) are back here.

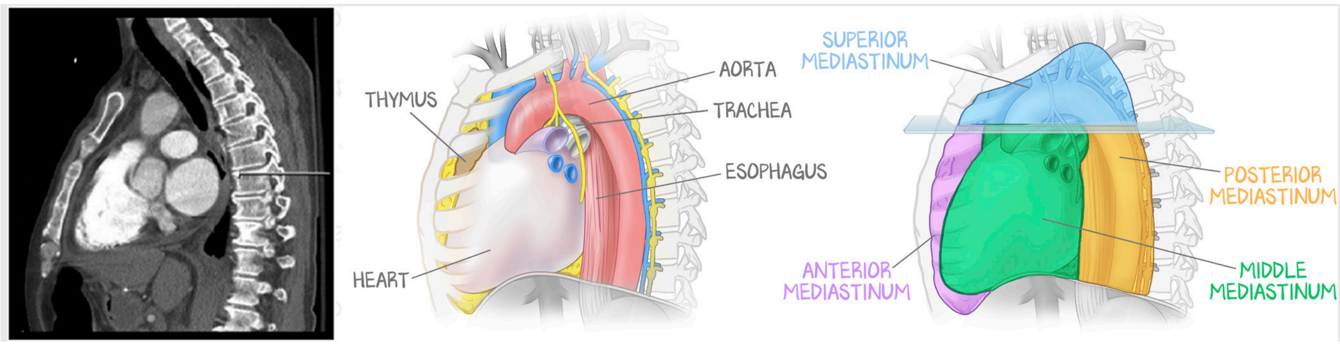

Figure 1.2: Order of the Mediastinum
The MRI shows the order of structures in an adult, whereas the illustrations show relative anatomy that is more closely aligned to real life and color-code the subdivisions of the mediastinum. Notice that the mediastinum is not an actual structure, merely a way of communicating relative anatomy.

The **superior mediastinum** has everything that is not the heart, and then some. Everything within the posterior inferior mediastinum originates or terminates above, below, or on both sides of the posterior inferior mediastinum. There are also structures within the superior mediastinum (pulmonary arteries and pulmonary veins) that are only in the superior mediastinum. Finally, there are structures that come from the neck but don't ever enter the inferior mediastinum (the trachea and blood vessels, lymphatics, and nerves to the upper extremity and head).

Location of the Heart Relative to the Chest Wall

The concept of the mediastinum isn't all that helpful and is notoriously convoluted, but it must be taught and memorized. We intentionally devoted the previous section to what is anterior or posterior to what while leaving out as much as possible about the orientation of the heart.

Now, we turn to the external anatomy and how you use it relative to the heart. We don't talk chambers, valves, or layers—we are just orienting you to geographic locations.

When anatomical surgeons (pathologists) would dissect a heart that was no longer in a human, the convention was to put the cardiac apex—the tip of the left ventricle—on the table. That way, it could be easily spun around, making it easier for the dissector to access difficult views. The apex is called the apex not because it's the most superior structure in the chest (it's not) but because the heart narrows here to a point, and *apex* means "point" or "tip." Every apex must have an accompanying base, and with the tip of the left ventricle as the apex, that base is formed by the exit points of the aorta and pulmonary artery. If you start at the apex and draw three lines around the heart, you get an inverted triangle: the flat part at the top is drawn across the exit point of the aorta and pulmonary artery—the base—and the other two lines converge at the tip of the left ventricle—the apex. *"Naturally,"* said the anatomists, *"the side opposite the apex is the base."* And so it came to be that the apex is on the bottom and the base is on the top.

Those who practice the art of medicine on living people still use the terms "apex" and "base," but to refer to something clinical. The clinical **apex** is in the fifth intercostal space, midclavicular line; this is where the **point of maximal impulse** (PMI) is palpated, it is the **mitral valve** position for auscultation and where you place a point-of-care ultrasound to get a four-chambered view of the heart. It is where the **left ventricle** is. The clinical **base** is located at the second intercostal space on either side of the sternal border and represents the auscultation location for the **aortic valve** (right border) and **pulmonic valve** (left border).

That was not an error. The aorta exits from the left ventricle on the right side of the chest then loops around the pulmonary artery to descend. The pulmonary artery exits from the right ventricle on the left side of the chest. That is because the **heart is rotated** into the **left side of the chest**. The most **anterior** structure is the **right ventricle**, which rests just **under the sternum**. The rightmost structure is the **right atrium**, which peeks out from behind the sternum to form the right heart shadow on a chest X-ray. The most **posterior** structure is the **left atrium**, which can impinge nearby structures, such as the trachea, esophagus, and aorta, if it becomes dilated. The leftmost structure is the **left ventricle**.

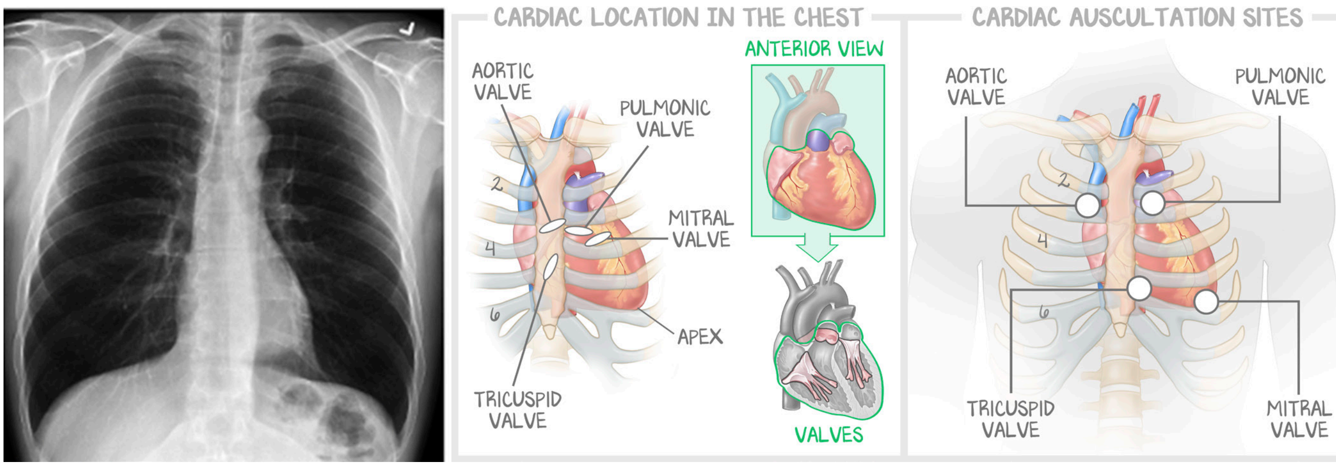

Figure 1.3: The Heart Relative to the Chest
A common misconception is that the heart is in the middle of the chest. The heart is rotated so that the right ventricle is the most anterior structure, located behind the sternum. The left ventricle is on the left side of the sternum. The relative locations of the valves enable clinicians to auscultate those valves with good repeatability between patients. Take the two-dimensional chest X-ray, then imagine where those oval-shaped valve markers would be on that X-ray, then imagine where the auscultation circles are on the X-ray, then finally find those sites on yourself, on your own external anatomy.

This information is useful when listening to the heart. The external anatomy shows you where to place your stethoscope to listen to each valve.

VALVE SOUND	WHERE TO HEAR IT
Aortic	2nd intercostal space, right sternal border, just lateral to the sternum
Pulmonary	2nd intercostal space, left sternal border, just lateral to the sternum
Tricuspid	4th intercostal space, just lateral to the xiphisternal joint
Mitral	5th intercostal space, midclavicular line, on the left, at the PMI

Table 1.1
Mnemonic: "All Physicians Take Money"

The Four Chambers of the Heart; the Two-Heart Model

The chambers and valves are discussed throughout the entire Plumbing island. However, we introduce the two-heart model now because we will routinely return to this model to explain both physiology and pathology. We're also giving you a break from the grueling anatomy.

Conceptually, you should think of the heart as two separate hearts: a left heart and a right heart, side by side but not connected. The left heart is connected to the systemic vasculature through the aorta. It is a high-pressure system that carries oxygenated blood to all tissues. The right heart is connected to the pulmonary vasculature and sends all of its blood through the lungs to be oxygenated before being returned to the left heart. This two-heart model allows for a separation of physiology and a discussion of resistance and explains why the left heart is so much bigger than the right.

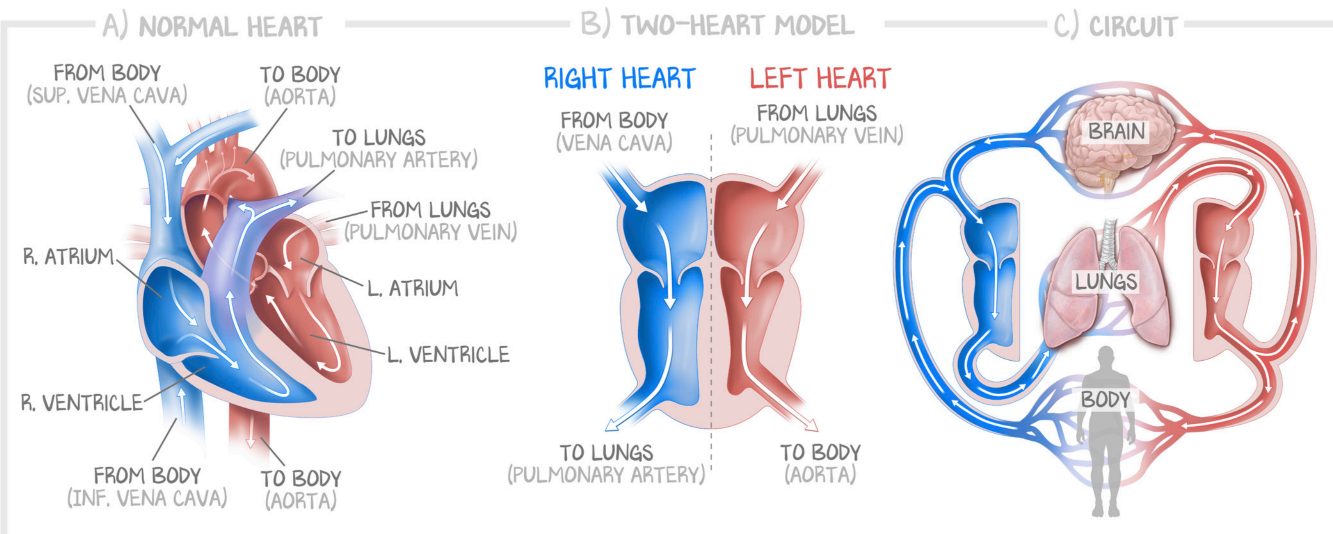

Figure 1.4: Two-Heart Model
(a) Normal anatomy of the heart, as seen with the front of the heart removed. The flow of blood is depicted with white arrows, right atrium to right ventricle, right ventricle to pulmonary artery. Then blood returns from the lungs to the left atrium, left atrium to left ventricle, left ventricle to the aorta. Notice how close the aorta and pulmonary artery are to each other and where the ventricular outflow is relative to the ventricles. (b) Two-heart model, illustrated with the aorta and pulmonary artery down, is anatomically inaccurate but makes it much easier to conceptually follow the flow of blood. (c) Using the two-heart model, we separate not just the right and left hearts but also the systemic and pulmonic circuits.

The two-heart model works because of the actual anatomy. There are **four cardiac chambers** with **four cardiac valves**. There are two atria. There are two ventricles. The ventricles are separated by an interventricular septum. That means the left and right ventricles have a solid wall between them, so they are functionally and anatomically separate. The atria are separated by an interatrial septum. That means the right and left atria have a solid wall between them, so they are functionally and anatomically separate. The atria are separated from the ventricles by a **fibrous band** of connective tissue called the **atrioventricular septum**. Myocardium does not cross this septum, although blood vessels and the cardiac conduction system do (details in the Electricity island). The **valves** cover the holes in the septum, and the annular rings of those valves are made of the same fibrous material as the septum. The right atrium and right ventricle are connected to each other. The left atrium and the left ventricle are connected to each other. Functionally, there are two hearts.

Valves ensure the unidirectional flow of blood. Normal blood flow is from the right atrium through the tricuspid valve into the right ventricle; from the right ventricle into the pulmonary artery through the pulmonic valve; from the pulmonary artery through the lungs, and back through the pulmonary veins into the left atrium. From the left atrium through the mitral valve into the left ventricle, the left ventricle pumps blood through the aortic valve into the aorta, to the entire body. That blood returns to the right atrium through the vena cava. Back to anatomy. Chambers and valves overview.

The Anatomy Inside the Heart

This will serve merely as a vocabulary builder. If this is your first encounter, don't worry if you feel overwhelmed. Don't feel like you have to master the content or go elsewhere to do deeper research. It will come in subsequent lessons. This is both an introduction and a summary.

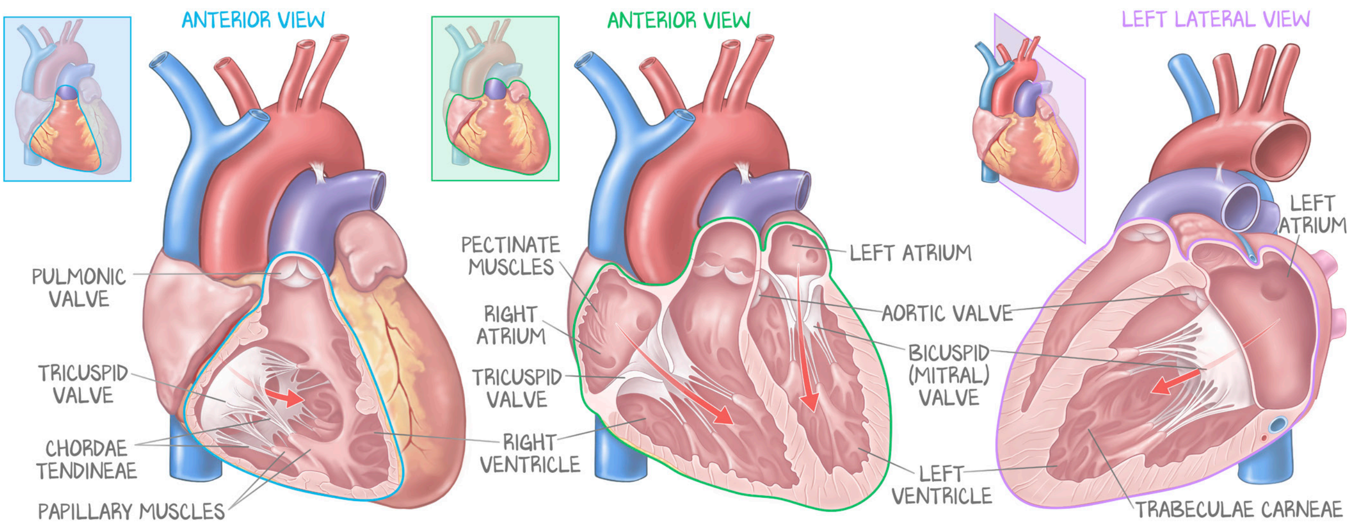

Figure 1.5: Inside Anatomy
The heart is an incredibly difficult structure because so much happens in such a small space. We told our illustrator to draw whatever views she wanted, then just remove what is in the way to show what we needed to see. In the first anterior view, you're looking at the open tricuspid valve, the red arrow coming from the right atrium into the right ventricle. The right ventricle has chordae tendineae that attach to papillary muscles, and the pulmonary artery (purple) and pulmonary valve can be seen up near the atria, in the middle of the heart. In the second anterior view, both the bicuspid (mitral) valve and tricuspid valve are shown. Behind the pulmonary artery is the aortic outflow tract (not visible). In the left lateral view, you see the left atrium and left ventricle clearly. The trabeculae carneae are the ridges of muscle. Notice that the aortic valve, the left ventricular outflow tract, is very close to the pulmonary valve at the top of the heart, near the atria.

This section is here for your reference. None of this information needs to be committed to memory right now. We just wanted to give you a tour of the structures and their relative spatial relationships.

The Four Valves

The specifics of valve function (Plumbing #2: *Cardiac Cycle*) and failure (Plumbing #3: *Valves*) are discussed in more detail later in the course.

There are two **atrioventricular valves**—the tricuspid and mitral valves—that separate the atria from their corresponding ventricles. They both work the same way—chordae tendineae and papillary muscles pull to resist the ejection of blood created by the ventricle. The **tricuspid valve** has **three leaflets**, whereas the **mitral valve** (bicuspid valve) has **two leaflets**.

Leaflet function is most easily explained through the example of the mitral valve. The mitral valve separates the left atrium from the left ventricle. The leaflets are made of **rigid fibrous tissue** and connected to (derived from) the fibrous atrioventricular septum. Their hinge is the opening of that septum. During diastole, blood is pulled down into the left ventricle by gravity. There is nothing to oppose this flow, and the mitral valve is pushed down into the ventricle as well. During ventricular contraction, blood is forcefully ejected up from the apex towards the ventricular outflow. This would push blood and the mitral valve leaflets back up into the atrium, but as the ventricle is contracting to expel blood, the **papillary muscles** (which is myocardium) are also contracting. The papillary muscles are attached to the leaflets by fibrous, tendon-like structures called **chordae tendineae**. As the papillary muscles contract, they resist the force that would push the leaflets into the atrium, pulling them back toward the ventricle. The force of ejecting blood prevents the papillary muscles from bringing the leaflets down, and the papillary muscles prevent the force of ejection from pushing the leaflets up into the atrium.

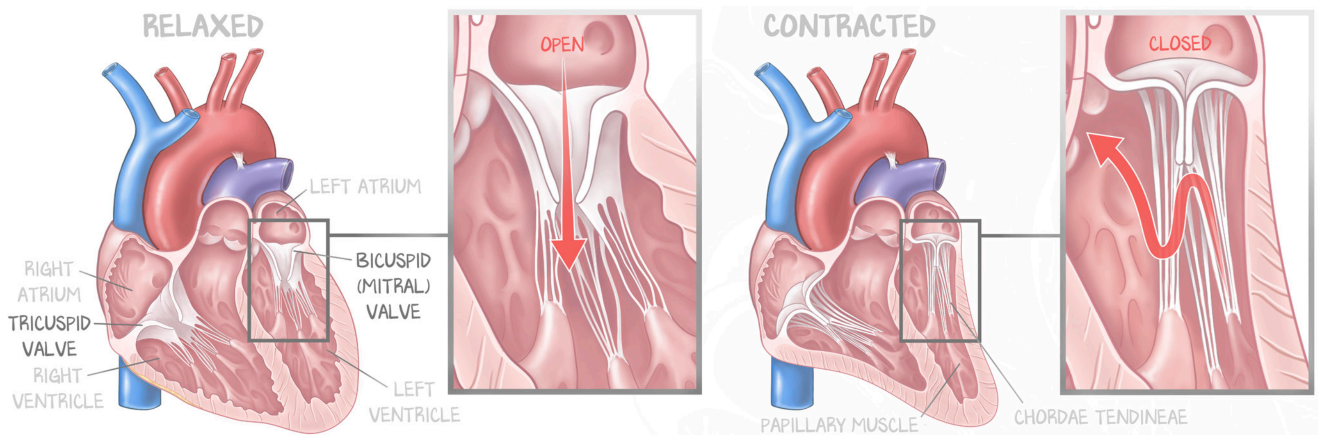

Figure 1.6: Atrioventricular Valves
When the left ventricle is relaxed, the bicuspid/mitral valve is passively opened by the flow of blood into the left ventricle from the left atrium. The chordae tendineae are slack and loose. The chordae tendineae are continuous with the fibrous tissue that makes up the valve. During contraction, the papillary muscles yank back on the leaflets while the force of ejection pounds into the leaflets. The net effect is the prevention of the blood from flowing into the atrium and its redirection out through the aortic valve instead. The same is true of the right atrium, tricuspid valve, and right ventricle.

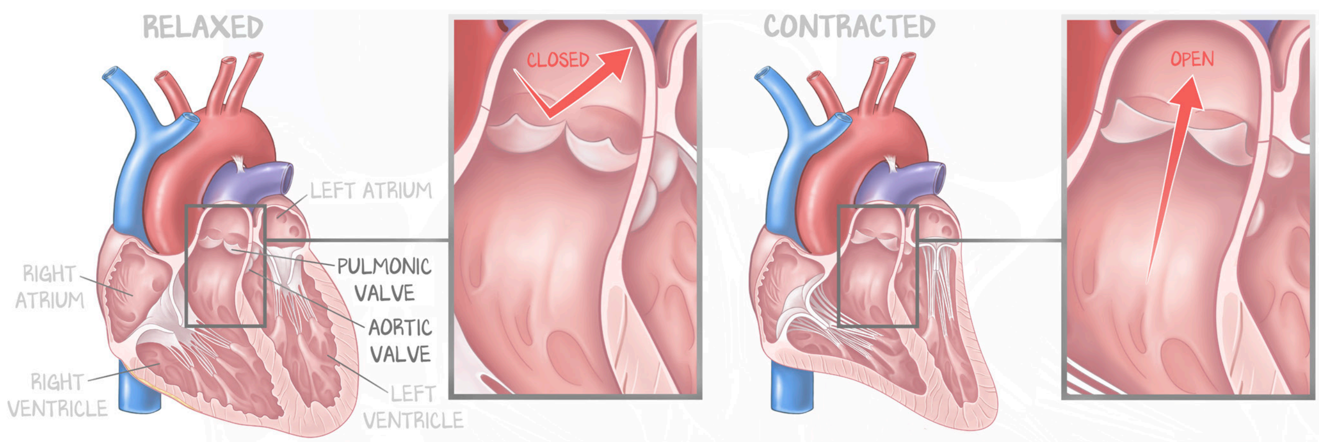

Figure 1.7: Semilunar Valves
There are no chordae tendineae attached to the semilunar valves. When the right ventricle is relaxed, the pulmonary artery is recoiling, translating perfusion pressure into the bloodstream. Blood flows in both directions, back toward the right ventricle and down the arterial tree. That perfusion pressure forces the leaflets of the pulmonic valve to slam into each other, preventing the backflow of blood into the right ventricle, ensuring that blood moves only down the arterial tree. The same is true for the left ventricle, aorta, and aortic valve.

There are two **semilunar valves**: the pulmonary and aortic valves. They don't have chordae tendineae or papillary muscles. Their three leaflets come together to close the gap. They close in diastole, when ventricular pressures fall, and aortic backpressure forces them closed. The fact that they don't have muscles to help them and they just slam shut against each other explains the pathogenesis of aortic stenosis—the thickening of the valve over time—and why it is the most common murmur in the elderly. The lesion develops due to high pressure and repeated trauma—every valve closure is another traumatic injury.

The Layers of the Heart

The heart has three layers: the **endocardium**, **myocardium**, and **epicardium**.

The heart is mostly muscle, and thus the **myocardium** is, by far, the largest layer. On either side of the myocardium, there is connective tissue, just as with all organs, through which blood vessels, lymphatics, and nerves run.

The chambers of the heart are where the blood is. And, like all structures that contain blood, the chambers of the heart are lined with **endothelium**—simple squamous epithelium and its associated basement membrane. Between the myocardium and endothelium is some connective tissue, with small blood vessels, lymphatics, and nerves. The endothelium and its connective tissue are called the **endocardium** (endo for the most inside, the deepest layer). Be careful not to conflate endothelium—the simple squamous epithelium that lines all blood-carrying structures—and endocardium—the innermost layer of the heart, which includes the endothelium.

Outside the myocardium is a layer of connective tissue through which the blood vessels, lymphatics, and nerves of the heart run. This connective tissue lies between the myocardium and the pericardial cavity and is called the **epicardium**. This connective tissue carries **autonomic nerves** and **epicardial arteries**, which branch to send penetrating arteries off into the myocardium.

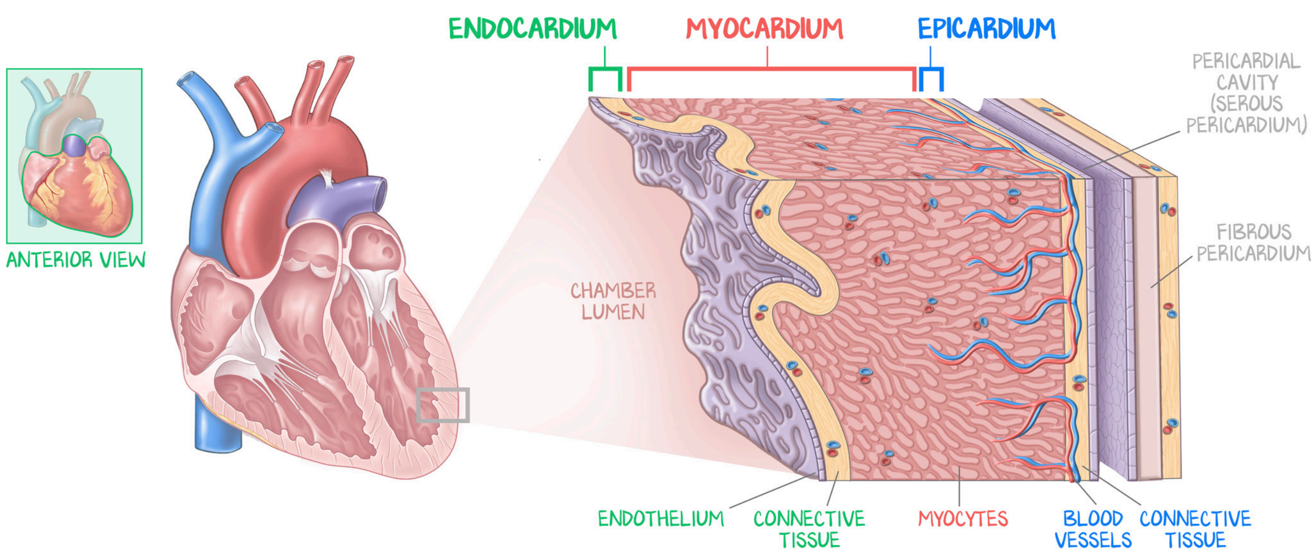

Figure 1.8: Layers of the Heart
Pay close attention to this figure and heed it well. Although we have intentionally distorted the relative size of these layers, we have preserved their relative directionality. The epicardial vessels penetrate the myocardium on the epicardial side, the fibrous pericardium and its connective tissue facing away from the pericardial cavity. The one pericardial cavity is between the fibrous pericardium and the loose connective tissue of the epicardium. You won't see other sources describe these structures this way, but this way is both accurate and easier to understand.

The **pericardial cavity** is next, separating the epicardium from the fibrous pericardium. The fibrous pericardium, with its connective tissue containing blood vessels, lymphatics, and nerves, is separated from the epicardium by the pericardial cavity. This discussion is continued in Structure and Function #3: *Pericardial Disease*.

The Conduction System and Blood Vessels

That is as much as you need for the Structure and Function island. This was a taste of things taught elsewhere in the Cardiac module. We left out the cardiac conduction system, coronary arteries, and pathology entirely so as to not overwhelm you. This is the first Cardiology island of the Cardiac module and was meant to be a vocabulary builder and introduction more than anything else.

The conduction system has a dedicated island, Electricity. The coronary vasculature is taught in Electricity #1: *Coronary Vessels and Cardiac Conduction.* Coronary pathology is the subject of the Coronary Artery Disease (CAD) island. And lastly, you've already been through blood vessels in general in Hemodynamics. The anatomy and histology of the blood vessels are discussed there.